DESCRIPTION

RADIATION IMAGING DEVICE FOR CORRECTING BODY
MOVEMENT, IMAGE PROCESSING METHOD, AND COMPUTER
PROGRAM

TECHNICAL FIELD

The present invention relates to a radiation imaging device, an image processing method for the radiation imaging device, and a computer program for causing the radiation imaging device to execute the image processing method. In particular, the radiation imaging device and the image processing method according to the present invention can be suitably used to reduce in radiography an artifact which occurs in a tomographic image due to movement of a body to be tested (this movement is called body movement hereinafter).

BACKGROUND ART

Fig. 9 is a diagram showing a concept of a cone beam X-ray CT (computed tomography) device in which a plane sensor is used.

In Fig. 9, an X-ray which is radiated from an X-ray source 901 is transmitted through a body 903 to be tested, and the transmitted X-ray is detected

by a plane sensor 902 provided at the position opposite to the X-ray source 901. Here, it should be noted that the body 903 to be tested is also called a subject 903 hereinafter. Then, as radiating the X-ray and detecting the radiated X-ray, the cone beam X-ray CT device executes control so that the X—ray source 901 and the plane sensor 902 together rotate around the subject 903. Alternately, it is possible to constitute the cone beam X-ray CT device so that the X—ray source 901 and the plane sensor 902 are fixed and instead the subject 903 itself rotates.

As above, when one rotation from 0° to 360° is executed, each of the X—ray source 901 and the plane sensor 902 stands again its initial position. Alternately, when the subject 903 rotates from 0° to 360°, the subject 903 faces the initial direction at the initial position.

Incidentally, at that time, the projected image initially acquired by the plane sensor 902 at the angle 0° has to be the same as the projected image acquired after the rotation of 360°.

However, in the actual radiography, there is no assurance that a patient being the subject 903 does not move. That is, if the patient moves during the radiography, the projected image initially

acquired by the plane sensor 902 at the angle 0° is resultingly different from the projected image acquired after the rotation of 360°. Therefore, if the tomographic image of the subject 903 is created

5   by using such different projected images, a streak artifact appears on the created tomographic image.

To reduce the artifact which appears due to such body movement, in the conventional X-ray CT device in which the one-dimensional sensor is used,

10   a method of correcting deviation or misregistration of the subject occurring due to its body movement by executing interpolation within a range of certain angles is known (for example, see Japanese Patent Application Laid-Open No. H06-114052).

15   Subsequently, this method will be explained with reference to Figs. 10A, 10B and 10C. Here, Figs. 10A to 10C show the method that the body movement is corrected by using a sinogram in which the channels of the detector are plotted on the

20   axis of abscissa and rotation angles are plotted on the axis of ordinate. Here, it should be noted that each of curved lines 1001 to 1003 on this sinogram indicates the trajectory of a certain point within the subject 903.

25   If the subject 903 does not move during the radiography (that is, there is no body movement of

4

the subject 903), as shown in Fig. 10A, a detector channel position A of the point at the time of a start of scan (0°) conforms to a detector channel position B on the point at the time of an end of the scan (360°). On the other hand, if the body movement of the subject 903 occurs, as shown in Fig. 10B, the detector channel position of the point at the time of the end of the scan (360°) which should be essentially the position B shifts to a position B'.

To correct such deviation or misregistration of the subject 903 occurring due to its body movement, as shown in Fig. 10C, the detector channel position A of the point at the time of the start of the scan (0°) is shifted to a position A' and the detector channel position B' on the point at the time of the end of the scan (360°) is likewise shifted to a position B" both by an amount half as much as a deviation amount between the detector channel position A of the point at the time of the start of scan (0°) and the detector channel position B' on the point at the time of the end of the scan (360°), so as to conform the position A' and the position B" to each other. Then, an interpolation process is executed to the data between the position A' and the position B" with

respect to all the channels to acquire the data
string as indicated by the dotted curved line 1003
shown in Fig. 10C.

By using the above method, in the conventional
5   X-ray CT device in which the one-dimensional sensor
is used, it is possible to reduce the artifact
which appears due to the body movement of the
subject 903. However, in the cone beam X-ray CT
device in which the plane sensor 902 is used, if
10   the above method is applied with respect to each of
the horizontal lines constituting the plane sensor
902, there is a problem that consistency between
the adjacent horizontal lines cannot be
sufficiently attained, whereby the body movement of
15   the subject cannot be accurately corrected
resultingly.

Moreover, if it is judged by using the
magnitude of deviation or misregistration of each
horizontal line whether or not the body movement of
20   the subject occurs, there is a problem that
accurate judgment for the body movement cannot be
attained, whereby there is a fear that the body
movement is needlessly corrected resultingly.

25   DISCLOSURE OF THE INVENTION
The present invention has been made in

consideration of the above problems, and the object
thereof is to high-accurately correct a body
movement as much as possible for reducing an
artifact which appears on a tomographic image.

5   A radiation imaging device according to the
present invention is characterized by comprising:
        a geometric transformation parameter solving
unit adapted to acquire, from among plural
projected images of which projected angles of a
10   radiation are different from others, geometric
transformation parameters between at least the two
projected images of which the projected angles of
the radiation overlap each other;
        a changing unit adapted to gradually change
15   the geometric transformation parameters acquired by
the geometric transformation parameter solving unit,
within a predetermined range of the projected
angles of the radiation; and
        a body movement correction unit adapted to
20   execute a correction of a body movement by
executing geometric transformation to the plural
projected images of which the projected angles of
the radiation are different, by using the
respective changed geometric transformation
25   parameters.

        Moreover, an image processing method according

to the present invention is characterized by comprising:

a geometric transformation parameter solving step of acquiring, from among plural projected images of which projected angles of a radiation are different from others, geometric transformation parameters between at least the two projected images of which the projected angles of the radiation overlap each other;

a changing step of gradually changing the geometric transformation parameters acquired in the geometric transformation parameter solving step, within a predetermined range of the projected angles of the radiation; and

a body movement correction step of executing a correction of a body movement by executing geometric transformation to the plural projected images of which the projected angles of the radiation are different, by using the respective changed geometric transformation parameters.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram showing one example of the whole constitution of an X-ray CT system according to the embodiment of the present invention;

Fig. 2 is a flow chart for explaining one example of the operation to be executed by the X-ray CT system in case of radiographing a subject and thus acquiring a tomographic image, according to the embodiment of the present invention;

Fig. 3 is a flow chart for explaining one example of the operation to be executed in a pre-process and a reconstruction process of the X-ray CT system, according to the embodiment of the present invention;

Fig. 4 is a conceptual diagram for explaining the corresponding points between two projected images of which the projected angles overlap each other, according to the embodiment of the present invention;

Fig. 5 is a conceptual diagram for explaining the fixed points on one of the two projected images of which the projected angles overlap each other, according to the embodiment of the present invention;

Figs. 6A and 6B are conceptual diagrams for explaining how to acquire the corresponding points by means of matching, according to the embodiment of the present invention;

Fig. 7 is a conceptual diagram for explaining geometric transformation parameters for correcting

body movement, according to the embodiment of the present invention;

Fig. 8 is a conceptual diagram for explaining the coordinates which show the status before the geometric transformation is executed and the coordinates which show the status after the geometric transformation was executed;

Fig. 9 is a conceptual diagram for explaining a conventional cone beam X-ray CT device; and

Figs. 10A, 10B and 10C are conceptual diagrams for explaining conventional geometric transformation parameters for correcting body movement.

BEST MODE FOR CARRYING OUT THE INVENTION

Hereinafter, the embodiment of the present invention will be explained with reference to the attached drawings.

Fig. 1 is a block diagram showing one example of the whole constitution of an X-ray CT system according to the embodiment of the present invention.

In Fig. 1, an X-ray is generated from an X-ray source (or X-ray generator) 103 which is controlled by an X-ray generator control unit 104, the generated X—ray is transmitted through a patient

102 which is treated as a subject, and the transmitted X-ray is then detected by an X-ray detector 101. Incidentally, in the present embodiment, the case where the X-ray is used will

5   be explained by way of example. However, it is needless to say that the radiation to be processed in the present embodiment is not limited to the X-ray, that is, electromagnetic waves such as an α-ray, a β-ray, a γ-ray and the like may be used.

10   The X-ray detected by the X-ray detector 101 is then input as a projected image to an image input unit 105. Incidentally, the X-ray source 103 and the X-ray detector 101 such as a plane sensor or the like collect the projected image with

15   respect to each of predetermined rotation angles as together rotating around the patient 102. However, it is alternatively possible to rotate the patient 102, as the subject, who is fixed to a rotary table, as maintaining the positional relation of the

20   patient 102 with respect to the X-ray source 103 and the X-ray detector 101.

Here, an image processing unit 107 corrects the X-ray detector 101, executes a pre-process including logarithmic transformation to the input

25   projected image of each of the rotation angles, and further executes image processes such as a

reconstruction process and the like to the input

projected image. Thus, a group of tomographic

images (or called a tomographic image group) is

created through the above processes. After then,

5   the created tomographic image group can be

displayed on a diagnostic monitor 109, and also

stored in an image storage unit 108. In addition,

it is possible to output the created tomographic

image group to a printer 112, a diagnostic work

10   station 113 or an image database 114 through a

network 111.

Incidentally, a tester or a diagnostician

handles an operation unit 110 to execute various

operations such as a display window operation on

15   the diagnostic monitor 109 or the like, a switching

display operation of the tomographic image in the

body axis of the patient 102, a cross section

transformation operation of the tomographic image,

a three-dimensional surface display operation, and

20   the like. In the present embodiment, the above

operations are totally managed by an X-ray

radiography system control unit 106 which consists

of a microcomputer and the like.

Fig. 2 is a flow chart for explaining one

25   example of the operation to be executed by the X-

ray CT system in case of radiographing the subject

(CT radiography) and thus acquiring the tomographic
image.

Initially, in a step S201, radiography
conditions such as an X-ray tube voltage, an X-ray
tube current, an exposure time and the like,
patient information such as a patient's name, a
patient's age, a patient's gender and the like, and
test information such as a test ID (identification)
and the like are set through the operation by the
tester on the operation unit 110.

Next, in a step S202, the X-ray generator
control unit 104 controls the X-ray source 103 in
accordance with the radiography conditions set in
the step S201. Thus, the X-ray is generated from
the X-ray source 103 to radiograph the patient 102,
and the projected image acquired by the radiography
is input to the image input unit 105.

Subsequently, in a step S203, the image
processing unit 107 executes the pre-process to the
projected image acquired in the radiography. Then,
in a step S204, the image processing unit 107
further executes the reconstruction process to the
projected image subjected to the pre-process in the
step S203. By doing so, the tomographic image of
the patient 102 is created.

After then, in a step S205, the tomographic

image created in the step S204 is displayed on the diagnostic monitor 109. Thus, the tester confirms the tomographic image displayed on the diagnostic monitor 109, and handles the operation unit 110 in accordance with the confirmed result. Subsequently, in a step S206, the X-ray radiography system control unit 106 judges whether or not it is indicated that the X-ray radiography succeeds, based on the content of the handling by the tester. Then, when the X-ray radiography system control unit 106 judges that it is indicated that the X-ray radiography does not succeed, the flow returns to the step S202 to again radiograph the patient 102. That is, the processes in the steps S202 to S206 are repeated until the X-ray radiography system control unit 106 judges that it is indicated that the X-ray radiography succeeds. On the contrary, when the X-ray radiography system control unit 106 judges that it is indicated that the X-ray radiography succeeds, the flow advances to a step S207. In the step S207, the X-ray radiography system control unit 106 transfers the tomographic image created in the step S205 to the image storage unit 108, the image database 114 and the like. Subsequently, in a step S208, the X-ray radiography system control unit 106 judges whether or not next

radiography is indicated, on the basis of the

handling by the tester on the operation unit 110.

Then, when the X-ray radiography system control

unit 106 judges that the next radiography is

5   indicated, the flow returns to the step S201 to

execute the next radiography. On the contrary, when

the X-ray radiography system control unit 106

judges that the next radiography is not indicated,

the operation to be executed by the X-ray CT system

10   ends.

Fig. 3 is a flow chart for explaining one

example of the operation to be executed in the pre-

process and the reconstruction process of the X-ray

CT system, according to the present embodiment.

15   In Fig. 3, at the first place, the coordinates

of the corresponding points between the two

projected images of which the projected angles

overlap each other are acquired (step S301). Here,

in the following, a concrete example of the process

20   to be executed in the step S301 will be explained.

More specifically, for example, if the set of

the X-ray source 103 and the X-ray detector 101

scans the patient 102 as just making a round (360°)

of the patient 102, the projected angles which

25   overlap each other may be set as 0° and 360°

respectively. Besides, if the set of the X-ray

source 103 and the X-ray detector 101 executes the scan of 360° or more ((360 + α)°), the projected angles which overlap each other may be set as θ° (< α) and (360 + θ)° respectively.

5   Then, Fig. 4 is a conceptual diagram for explaining the corresponding points between the two projected images of which the projected angles overlap each other. That is, as shown in Fig. 4, the coordinates of the corresponding points (the

10   small black square points shown in Fig. 4) between a projected image 401 (for example, an image at scan angle 0°) and a projected image 402 (for example, an image at scan angle 360°) of which the respective projected angles overlap each other are

15   acquired. Here, it should be noted that the number of corresponding points has to be equal to or larger than the number of geometric transformation parameters, and accuracy of the geometric transformation parameters improve in proportion to

20   increase in the number of corresponding points.

However, if the number of corresponding points increases, a necessary calculation time becomes long at the same instant. Therefore, in consideration of such a fact, it has only to

25   determine the number of corresponding points substantially in accordance with the system itself.

In any case, the sets of the coordinates of the respective corresponding points of the projected images 401 and 402 are acquired as much as the number of corresponding points. To achieve this, first, plural fixed points are set on one (e.g., projected image 401) of the two projected images. Here, for example, it is preferable to use the most characteristic points as the fixed points. For example, with respect to the image of a chest, the end points of a rib, the branch points of lung blood vessels, and the like are suitable for the most characteristic points. Therefore, the end points of the rib, the branch points of the lung blood vessels or the like are set as the fixed points. In contrast, even if the characteristic points are not used as the fixed points, for example, as shown in Fig. 5, it has only to divide the entirety of the projected image 401 into numbers of small rectangles, and then set the respective central points of the divided small rectangles within the range of the subject as the fixed points.

Thus, if the plural fixed points are set with respect to one of the two projected images, the coordinates, on the other (e.g., projected image 402) of the two projected images, of the points

respectively corresponding to these fixed points
are acquired. To achieve this, it has only to use a
matching method which is generally used in stereo
analysis and the like. Hereinafter, an example of

5   how to acquire the sets of the corresponding points
by using the matching method will be explained with
reference to Figs. 6A and 6B.

As shown in Fig. 6A, a template image 603 of a
predetermined size is cut out on the basis of the

10   fixed point on the projected image 401. Then, as
shown in Fig. 6B, a search area 604 of a
predetermined size larger than the size of the
template image 603 is set on the projected image
402 of which the projected angle overlaps the

15   projected angle of the projected image 401. Here,
it should be noted that the coordinates of the
central point of the search area 604 are the same
as the coordinates of the fixed point on the
projected image 401.

20   Then, the position of the central point is
shifted sequentially from the upper left to the
lower right within the search area 604. At the same
time, a reference image of the size same as that of
the template image 603 is cut out from the

25   projected image 402. Subsequently, an estimated
value est concerning the matching between the cut-

out reference image and the template image 603 is acquired.

Here, if it is assumed that the coordinates of the reference image are given as r(x, y) and the coordinates of the template image 603 are given as t(x, y), the estimated value est of the matching can be acquired by the following equation (1).

$$est = \frac{\sum_{k=1}^{n}\sum_{l=1}^{m}\{r(k,l)-\bar{r}\}\cdot\{t(k,l)-\bar{t}\}}{\sqrt{\sum_{k=1}^{n}\sum_{l=1}^{m}\{r(k,l)-\bar{r}\}^2}\cdot\sqrt{\sum_{k=1}^{n}\sum_{l=1}^{m}\{t(k,l)-\bar{t}\}^2}} \quad \cdots (1)$$

Here, it should be noted that, in the above equation (1), the symbols n and m respectively denote pixel sizes of the template image 603, and the horizontal lines (-) added above the characters (r and t) indicate the respective average values.

Incidentally, when it is requested to execute the calculation at high speed, the estimated value est of the matching may be acquired simply by the following equation (2).

$$est = \sum_{k=1}^{n}\sum_{l=1}^{m}|r(k,l)-t(k,l)| \quad \cdots (2)$$

That is, the position of the reference image at which the estimated value est of the matching

becomes minimum is equivalent to the coordinates of the corresponding points.

In any case, when the coordinates of the corresponding points between the projected images 401 and 402 of which the projected angles overlap each other are acquired in the step S301, the geometric transformation parameter is acquired from the set of the coordinates of the corresponding points (step S302). For example, affine transformation may be used in such geometric transformation.

It should be noted that the affine transformation can be represented by the following equation (3).

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} a_{01} \\ a_{02} \end{pmatrix} \cdots (3)$$

Then, the set of the corresponding points is defined as the set of the point of the coordinates (x_n, y_n) and the point of the coordinates (X_n, Y_n) (n is 1, ..., N). Subsequently, geometric transformation parameters a_{01}, a_{02}, a_{11}, a_{12}, a_{21}, a_{22} for the affine transformation by which a least squares error err between the coordinates (x_n', y_n') acquired by transforming the coordinates (x_n, y_n)

with use of the above equation (3) and the coordinates (X_n, Y_n) is minimized are acquired. Incidentally, the least squares error err is represented by the following equation (4).

5

$$err = \sum_{n=1}^{N} \sqrt{(X_n - x'_n)^2 + (Y_n - y'_n)^2} \cdots (4)$$

Here, the coordinates x_n' and y_n' are the functions which use the geometric transformation

10 parameters a_{01}, a_{02}, a_{11}, a_{12}, a_{21}, a_{22} for the affine transformation as variables. Therefore, also the least squares error err by the equation (4) is the function which uses the geometric transformation parameters a_{01}, a_{02}, a_{11}, a_{12}, a_{21}, a_{22} for the affine

15 transformation as variables.

For this reason, if the least squares error err is subjected to partial differentiation based on each of the variables of the geometric transformation parameters a_{01}, a_{02}, a_{11}, a_{12}, a_{21}, a_{22}

20 for the affine transformation to set "0" and then the simultaneous equations are solved, it is possible to acquire the geometric transformation parameters a_{01}, a_{02}, a_{11}, a_{12}, a_{21}, a_{22} for the affine transformation by which the least squares error err

25 becomes minimum.

In this way, when the affine transformation is

executed, the geometric transformation parameters a_{01}, a_{02}, a_{11}, a_{12}, a_{21}, a_{22} for the affine transformation are acquired. However, when the affine transformation is executed, the geometric

5   transformation in which also enlargement of the image and shearing of the image are admitted. Consequently, in case of executing the geometric transformation only for rotation of the image and movement of the image without permitting the

10   enlargement of the image and the shearing of the image, Helmert transformation is used. Here, it should be noted that the Helmert transformation can be represented by the following equation (5).

15
$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} a_{01} \\ a_{02} \end{pmatrix} \cdots (5)$$

That is, the geometric transformation parameters in case of the Helmert transformation are three, i.e., θ, a_{01}, a_{02}. Therefore, these

20   parameters can be acquired in the same manner as above.

In addition to the affine transformation and the Helmert transformation, even if secondary projective transformation, high-order polynomial

25   transformation or the like is used, it is possible to acquire the geometric transformation parameters

as well as the case where the affine transformation, the Helmert transformation or the like is used.

In any case, when the geometric transformation parameter is acquired in the step S302, it is then judged whether or not an estimated amount of the acquired geometric transformation parameter is larger than a predetermined amount (step S303).

Here, it should be noted that the estimated amount of the geometric transformation parameter is the amount for estimating the magnitude of the body movement while the scan is being executed. More specifically, the estimated amount of the geometric transformation parameter is used to estimate how far from the geometric transformation parameter in case of no body movement.

Incidentally, for example, it is assumed that the geometric transformation parameters are set as λ_1, λ_2, ..., λ_n, ..., λ_N, and the geometric transformation parameters in case of no body movement are set as λ_1', λ_2', ..., λ_n', ..., λ_N'. On such a premise, an estimated amount est2 of the geometric transformation parameter can be acquired by the following equation (6).

$$est2 = \sqrt{\sum_{n=1}^{N}(\lambda_n' - \lambda_n)^2} \cdots (6)$$

Here, it should be noted that the right side
of the above equation (6) may not be necessarily
the square root. That is, instead of the above
equation (6), it is possible to more simply acquire

5   the estimated amount est2 of the geometric
transformation parameter by the following equation
(7).

$$est2 = \sum_{n=1}^{N} |\lambda_n' - \lambda_n| \cdots (7)$$

10

By the way, if the affine transformation is
adopted as the geometric transformation, the
following equations (8) are satisfied.

$\lambda_1 = a_{01}$, $\lambda_2 = a_{02}$, $\lambda_3 = a_{11}$, $\lambda_4 = a_{12}$, $\lambda_5 = a_{21}$,

15     $\lambda_6 = a_{22}$

$\lambda_1' = 0$, $\lambda_2' = 0$, $\lambda_3' = 1$, $\lambda_4' = 0$, $\lambda_5' = 0$, $\lambda_6' = 1$

... (8)

Moreover, if the Helmert transformation is
adopted as the geometric transformation, the

20   following equations (9) are satisfied.

$\lambda_1 = \theta$, $\lambda_2 = a_{01}$, $\lambda_3 = a_{02}$

$\lambda_1' = 0$, $\lambda_2' = 0$, $\lambda_3' = 0$ ... (9)

In any case, when it is judged in the step
S303 that the estimated amount of the geometric

25   transformation parameter acquired as above is equal
to or smaller than a predetermined amount, it is

possible to judge that there is no body movement of
the level for which the correction is necessary.
Therefore, in this case, the flow advances to a
step S306 without executing the correction of the
5   body movement so as to reconstruct the projected
image and thus create the tomographic image.

On the other hand, when it is judged in the
step S303 that the estimated amount of the
geometric transformation parameter acquired as
10   above is larger than the predetermined amount, the
correction of the body movement is executed.

More specifically, to execute the correction
of the body movement, the geometric transformation
parameter for geometric correction is first
15   determined so that the projected images of which
the projected angles overlap each other conform to
each other and gradually change within a
predetermined angle (step S304).

In the correction of the body movement, only
20   half of the correction amount is gradually
subjected to the correction according to the angles
within the range, e.g., from 0° to 180°.
Subsequently, within the range from 180° to 360°,
the correction is gradually executed according to
25   the angles in the direction opposite to the
direction of the correction within the rage from 0°

to 180°, whereby it is possible to achieve the smooth correction of the body movement.

With respect to the geometric transformation parameters for executing the above correction of the body movement (geometric correction), only half of the geometric transformation parameters acquired in the step S302 may be determined so as to gradually change within the range, e.g., from 0° to 180°. Besides, only half of the minus geometric transformation parameters acquired in the step S302 may be determined so as to gradually change within the range, e.g., from 180° to 360°.

In addition, the body movement is gradually corrected according to the angles within the range from 0° to 90°, by half of the correction amount of the body movement. Within the range from 90° to 270°, the body movement is not corrected. Then, within the range from 270° to 360°, the body movement is gradually corrected according to the angles, by half of the correction amount of the body movement, in the direction opposite to the direction of the correction within the rage from 0° to 90°.

More specifically, the meaning that the projected image gradually changes within the predetermined angle and the body movement is

gradually corrected according to the angles is as follows. That is, the geometric transformation parameter is divided by the predetermined angle to acquire a change amount of the geometric

5   transformation parameter with respect to each unit angle, and the change amounts of the geometric transformation parameters of the respective unit angles are gradually added to others.

Here, one example of the method of determining

10   the geometric transformation parameters for executing the correction of the body movement (geometric correction) will be explained with reference to Fig. 7.

That is, Fig. 7 shows the projected angles in

15   the direction along the axis of abscissas and the geometric transformation parameters in the direction along the axis of ordinate, with respect to each of the respective geometric transformation parameters. In Fig. 7, the angles from 0° to 360°

20   are given as the projected angles. However, when the scan of an angle exceeding 360° $((360 + \alpha)°)$ is executed, the projected angle may be set from θ° $(< \alpha)$ to $(360 + \theta)°$.

Here, it takes the case of n-th parameter as

25   an example. The geometric transformation is executed by half of the body movement with respect

to the projected image of 0°, whereby its parameter $\mu_n(0)$ is given by the following equation (10).

$$\mu_n(0) = \lambda_n' + (\lambda_n - \lambda_n')/2 \qquad \qquad \dots (10)$$

Then, for example, it is assumed that the above predetermined angle is $\omega°$. In such a case, since the geometric transformation is not executed within the range from $\omega°$ to $(360 - \omega)°$, the parameter of the projected angle within this range is assumed as λ_n' for the sake of convenience. Here, within the range from 0° to $\omega°$, it is controlled to gradually change the parameter from $\mu_n(0)$ to λ_n'. That is, the parameter $\mu_n(\beta)$ in case of $\beta°$ $(< \omega)$ is given by the following equation (11).

$$\mu_n(\beta) = \lambda_n' + \{(\lambda_n - \lambda_n')/2\} \times \beta/\omega \qquad \dots (11)$$

Similarly, the geometric transformation is executed by half of the body movement with respect to the projected image of 360°, whereby its parameter $\mu_n(360)$ is given by the following equation (12).

$$\mu_n(360) = \lambda_n' - (\lambda_n - \lambda_n')/2 \qquad \qquad \dots (12)$$

Then, within the range from $(360 - \omega)°$ to 360°, it is controlled to gradually change the parameter from λ_n' to $\mu_n(360)$. That is, the parameter $\mu_n(\gamma)$ of the range from $(360 - \omega)°$ to 360° is given by the following equation (13).

$$\mu_n(\gamma) = \lambda_n' + \{(\lambda_n - \lambda_n')/2\} \times \{\gamma - (360 - \omega)\}/\omega$$

... (13)

These parameters are respectively used to execute the geometric correction by half with respect to the side of 0° and also to execute the geometric correction by half with respect to the side of 360°. However, the parameter may be determined so that the whole transformation is executed within the predetermined angle with respect to either the side of 0° or the side of 360°.

Then, when the geometric transformation parameters for correcting the body movement are acquired, the geometric transformation is executed to the projected image of each of the projected angles by using the acquired geometric transformation parameter (step S305). However, it should be noted that the geometric transformation is not executed within the range from ω° to $(360 - \omega)$°.

Subsequently, one example of the geometric transformation will be explained with reference to Fig. 8. In Fig. 8, it is assumed that, through the geometric transformation, a point (X, y) indicated by numeral 803 on a projected image 801 which is acquired before the geometric transformation is executed (hereinafter, called before-geometric

transformation image 801) is transformed into a point (X', y') indicated by numeral 804 on a projected image 802 which is acquired after the geometric transformation is executed (hereinafter,

5   called after-geometric transformation image 802).

When an image is created through the geometric transformation, the process opposite to the above is used. That is, the point (X, y) on the before-geometric transformation image 801 to be

10   transformed into the point (X', y') on the after-geometric transformation image 802 is acquired. Here, it should be noted that the point (X', y') indicates the coordinates of the integer value corresponding to each pixel on the after-geometric

15   transformation image 802. Then, by using the inverse transformation of the geometric transformation with respect to the coordinates, the point (X, y) corresponding to the point (X', y') can be acquired. However, since the point (X, y)

20   does not have the coordinates of an integer value, interpolation is executed by using the pixel values of the four points closest to the point (X, y), and the interpolated value is set as the pixel value of the point (X', y'). This process is executed to all

25   the pixels, whereby the image can be created through the geometric transformation.

Incidentally, when the image is created through the geometric transformation as above, the geometric transformation is not directly used, but the inverse transformation of the geometric

5   transformation is used. For this reason, the geometric transformation parameter may be set in advance as the parameter for the inverse transformation of the geometric transformation in the step S304.

10   In any case, when the correction of the body movement through the geometric transformation ends, the reconstruction is executed by using the corrected projected images, and the tomographic image is thus created (step S306).

15   As described above, in the present embodiment, the coordinates of the respective corresponding points between the projected images 401 and 402 of which the respective projected angles (for example, 0° and 360°) overlap each other are first acquired.

20   Then, the geometric transformation parameters $\mu_n(0)$ and $\mu_n(360)$ are acquired through the affine transformation or the like by using the sets of the coordinates of the corresponding points. Subsequently, when the estimated amount of the

25   geometric transformation parameter is larger than the predetermined amount, the correction of the

body movement is executed, and the tomographic image is then created by using the projected image 802 which has been subjected to the correction of the body movement.

More specifically, when the correction of the body movement is executed, as described above, the geometric transformation parameter for executing the geometric correction with respect to the projected angles from $\omega°$ to $(360 - \omega)°$ is assumed as λ_n' for the sake of convenience. Then, the geometric transformation parameter $\mu_n(\beta)$ for executing the geometric correction is determined so that the parameter gradually changes from $\mu_n(0)$ to λ_n' (as indicated by the equation (11)) within the range of the projected angles from $0°$ to $\omega°$. Moreover, the geometric transformation parameter $\mu_n(\gamma)$ for executing the geometric correction is determined so that the parameter gradually changes from λ_n' to $\mu_n(360)$ (as indicated by the equation (13)) within the range of the projected angles from $(360 - \omega)°$ to $360°$. After then, the geometric transformation (i.e., body movement correction) is executed to the projected images having the projected angles from $0°$ to $\omega°$ and to the projected images having the projected angles from $(360 - \omega)°$ to $360°$.

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As described above, according to the present
embodiment, the body movement (that is, the
movement of the subject) is not grasped with
respect to each horizontal (landscape) line, but
5   the body movement is grasped as the image. Thus,
the body movement can be accurately grasped and
seized, whereby it is possible to achieve high-
precision correction of the body movement, and it
is also possible to achieve the smooth correction
10   of the body movement. In consequence, it is
possible to create the tomographic image on which
an artifact has been reduced by correcting the body
movement.

(Other Embodiments Of The Present Invention)
15   Incidentally, the present invention includes
in its category a case where the program codes of
software for realizing the functions of the above
embodiment is supplied to a computer provided in an
apparatus or a system connected to various devices
20   so as to actually operate these devices for
realizing the functions of the above embodiment,
and thus the computer (CPU or MPU) in the system or
the apparatus reads and executes the supplied and
stored program codes and operates these devices.

25   In this case, the program codes themselves of
the software realize the functions of the above

embodiment. Therefore, the program codes themselves and a means, such as a recording medium storing these program codes, for supplying the program codes to the computer constitute the present

5   invention. As the recording medium for storing these program codes, for example, a flexible disk, a hard disk, an optical disk, a magnetooptical disk, a CD-ROM, a magnetic tape, a nonvolatile memory card, a ROM or the like can be used.

10   Moreover, it is needless to say that the present invention includes not only a case where the functions of the above embodiment are realized by executing the supplied program codes with the computer, but also a case where the program codes

15   cooperate with an OS (operating system) running on the computer or another application software to realize the functions of the above embodiment.

Furthermore, it is needless to say that the present invention also includes a case where, after

20   the supplied program codes are written into a function expansion board inserted in the computer or a memory of a function expansion unit connected to the computer, the CPU or the like provided in the function expansion board or the function

25   expansion unit executes a part or all of the actual processes on the basis of the instructions of the program codes, and thus the functions of the above

embodiment are realized by such the processes.

According to the present embodiment, the body movement can be grasped as the image. Thus, the body movement can be accurately grasped and seized. In addition, the geometric transformation parameters are smoothly changed between the projected angles, whereby it is possible to achieve high-precision correction of the body movement as much as possible. In consequence, it is possible to create the tomographic image on which an artifact has been reduced as much as possible.

According to another aspect of the present invention, the magnitude of the body movement is estimated by using the acquired geometric transformation parameters, and the correction of the body movement is executed only in the case where the magnitude of the body movement is equal to or larger than the predetermined magnitude. Thus, useless correction of the body movement can be avoided, whereby it is possible to shorten the time necessary for executing the correction of the body movement.

This application claims priority from Japanese Patent Application No. 2004-141490 filed May 11, 2004, which is hereby incorporated by reference herein.